US-Japan Joint Institute for Fusion Theory
Annual Report of Activities
April 1, 1994–March 31, 1995

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1. Introduction

The US-Japan Fusion Research Collaboration is organized under three programs: the Fusion Physics Planning Committee (FPPC), the Fusion Technology Planning Committee (FTPC), and the Joint Institute for Fusion Theory (JIFT).

The objectives of the JIFT program are: (1) to advance the theoretical understanding of plasmas, with special emphasis on stability, equilibrium, heating, and transport in magnetic fusion systems; and (2) to develop fundamental theoretical and computational tools and concepts for understanding nonlinear plasma phenomena. Both objectives are pursued through collaborations between U.S. and Japanese scientists, by means of various types of exchange program activities.

At present the JIFT program every year usually consists of four topical workshops (two in each country), six exchange scientists (three from each country), and a fluctuating number of joint computational projects (on the order of a dozen). So far, during its 14 years of successful operation, it has sponsored 79 long-term visits by exchange scientists, 50 topical workshops, and 51 joint computational projects.

The workshops typically have an attendance of 25–35 participants, of whom usually from five to seven scientists (depending on the particular workshop) travel to the workshop from the non-host country. Scientists from countries other than the U.S. and Japan are also often invited to participate in JIFT workshops, either as “observers” or multi-laterals.

Of the three exchange visitors in each direction every year, two (called “Exchange Scientists”) are supported by the sending country, and one (called “JIFT Visiting Professor”) is supported by the host country. The Exchange Scientists’ visits normally last a month or two, whereas the Visiting Professors normally stay for at least three months.

The third category of JIFT exchange activities are joint computational projects. These have generally arisen out of the JIFT workshops and exchange visits as continuing collaborations on various problems of interest.

The topics and also the participating scientists for the JIFT exchange visits, workshops, and joint computational projects are chosen with attention paid to having a balanced representation of critical issues in magnetic fusion research, including both fundamental problems as well as questions of near-term significance, and taking into account the specific capabilities and interests of both countries. The Japanese and US members of the JIFT Steering Committee agree together on the appropriateness of proposed topics before recommending them.

A number of general benefits have resulted over the years from the JIFT program, including the following: JIFT has provided efficient communication channels for the latest theoretical research results, techniques, and directions; JIFT activities have attracted serious participation from allied fields such as fluid turbulence, statistical physics, computational science, and space plasma physics, which brings new scientific tools into the fusion program and enhances the stature of fusion physics; JIFT exchanges have contributed to efficient utilization of international research facilities; and JIFT emphasis on large-scale computational studies has reaped significant mutual benefits from the supercomputer resources and code-building expertise of both countries.

A brief description of JIFT administration is given in Sec. 2 of this report. The current status of the various activities in the 1994-95 JIFT program is explained in Sec. 3. Highlights of specific technical accomplishments during the past year are given in Sec. 4. Plans for recommended activities during the next year are described in Sec. 5.

2. Management Structure

JIFT has a Steering Committee with eight members, four from each country, including two co-chairmen. The co-chairman on the Japanese side is the director of the Theory and Computer Simulation Center at The National Institute for Fusion Science (NIFS) in Japan, and the co-chairman on the US side is the director of the Institute for Fusion Studies (IFS) of The University of Texas at Austin. Two other members of the Steering Committee, who are called co-executive secretaries, have the day-to-day responsibility for overseeing the progress of JIFT activities. Furthermore, on the Japanese side, there are an official Advisor, who is from the Japan Atomic Energy Research Institute; and on the US side there is an Advisory Committee comprised of several members. The names of the persons on the Steering Committee and of the Advisors are given below:

JIFT Steering Committee

US Members	**Japanese Members**
R. Hazeltine (IFS)—Co-Chairman	T. Sato (NIFS)—Co-Chairman
J. Van Dam (IFS)—Co-Exec. Secretary	M. Okamoto (NIFS)—Co-Exec. Secretary
W. Sadowski (DOE)	M. Wakatani (Kyoto)
J. Dawson (UCLA)	K. Mima (Osaka)

Japanese Advisor: M. Azumi (JAERI)

US Advisory Committee: A. Aydemir (IFS), J. Johnson (PPPL), W. Horton (IFS), J. Leboeuf (ORNL), T. Tajima (IFS), and P. Terry (Wisconsin)

The Steering Committee attempts to schedule workshops to dovetail with other meetings, to continue to involve participation at workshops by interested experimentalists, and to invite relevant available scientists from other countries to attend workshops.

As the central vehicle for fundamental theoretical exchanges, JIFT operates alongside the Fusion Physics Planning Committee (FPPC) and the Fusion Technology Planning Committee (FTPC). The JIFT activities are coordinated with the four FPPC areas of activity, viz., core plasma phenomena, edge behaviour and control, heating and current drive, and new approaches and diagnostics. As part of this coordination, the US co-executive secretary attended a meeting of the FPPC held at General Atomics in San Diego on January 28, 1995.

3. Status of Current Activities

Every one of the workshops and personnel exchange visits that were scheduled in the 1994-95 annual JIFT program (see Attachment A) either has already occurred or soon will.

To date, three of the four workshops in the 1994-95 program have already been held:

- The workshop on *Fast Particle Physics and MHD Activities in Magnetic Confinement Systems* was held December 12-16, 1994, in Mito, Japan, attended by 6 US scientists, 30 Japanese scientists, and 4 scientists from other countries (Italy, Korea, Russia, and Sweden).
- The workshop on *Strong Electromagnetic Field Interactions with Plasmas* was held August 29 and 30, 1994, at the University of Maryland, College Park, US, attended by 11 US scientists and 6 Japanese scientists.
- The workshop on *Theoretical Studies of Bootstrap Currents in Toroidal Devices* was held November 2-4, 1994, in Atlanta, US, attended by 22 US scientists and 8 Japanese scientists.

A fourth workshop, on *Micro- and Macro-Scale Simulation*, is planned to be held in Nagoya, Japan, during March 13–17, 1995.

The annual meeting of the JIFT Steering Committee was held in the US, on November 7, 1994, during the annual meeting of the APS Division of Plasma Physics in Minneapolis. All eight steering committee members attended. Several members of the US JIFT Advisory Committee and also several Japanese observers were also in attendance at this meeting.

Of the six planned scientific personnel exchanges in the 1994-95 program, to date four of them have taken place, one is currently underway, and the last one is scheduled for next month. Dr. Yoshiomi Kondoh spent three months as a JIFT Visiting Professor at the Institute of Fusion Studies, with a visit to the University of Wisconsin. Dr. Hiroshi Naitoh spent three months as an exchange scientist at Princeton Plasma Physics Laboratory. Dr. Katsuji Ichiguchi's one-month visit to the IFS and Princeton was rescheduled to March. Dr. Gary Kerbel is currently spending three months as a JIFT Visiting Professor at NIFS. Dr. Guo-Yong Fu just finished visiting JAERI for one month as an exchange scientist. Dr. Nathan Mattor visited the University of Kyoto and NIFS for one month as an exchange scientist.

The various joint computational projects have also been active during the past year. Several involved some limited travel. One involved a twelve-month visit by a JAERI scientist, Dr. Masatoshi Yagi, to the IFS.

4. Technical Progress Highlights

The JIFT workshops during the past year were on topics of high interest and had a stimulating mix of analytical and numerical theorists, as well as some experimentalists, as participants.

- One of the workshops focused on the subject of bootstrap current, a very important topic for both tokamak and stellarator systems. Of the 24 talks given at the meeting, there were 7 on helical systems, 15 on tokamaks, and 2 on spherical tori. Five of the talks were experimental, and of the 19 theory talks, 9 were analytical and 10 were computational. Various talks included applications to ITER, TPX, LHD, TFTR, DIII-D, JT-60U, and proposed tight-aspect-ratio devices. Also, several of the talks were about active US-Japanese collaborations. Reactor specialists described what are their needs and expectations for bootstrap current in fusion reactors; experimentalists presented their empirical observations of bootstrap currents; and theorists offered appropriate explanations—with all agreeing that these currents are well modeled neoclassically.
- The workshop on electromagnetic interactions in plasmas was directed at physics areas of common interest to both rf experts in magnetic fusion and laser experts in inertial confinement. This provided opportunities for cross-field synthesis and was very successful.
- The workshop on fast particle physics was quite timely, due to its relevance to ongoing deuterium-tritium experiments on TFTR and recent ICRH-produced fast minority ion experiments on JT-60U, as well as to the possibility of energetic ion effects in LHD and to the negative-ion neutral beams planned for installation on JT-60U and Super Upgrade. Significant theory work on fast ion physics is being done for both tokamaks and helical toroidal systems. Of the 24 talks given at the meeting, 5 were about helical devices, 18 about tokamaks, and 1 talk about both. There were 8 experimental talks and 16 theory talks (5 computational and 11 analytical).

The various JIFT exchange visits were also productive, in terms of collaborations established, research accomplished, and papers written.

- Dr. Kondoh continued his numerical studies of nonlinear self-organization based on the minimum dissipation principle. He simulated Korteweg-deVries solitons in the presence of viscous dissipation and found that the dominant self-organization mechanism is initially energy transfer but later selection dissipation. A paper describing these results has been written.
- Dr. Naitoh collaborated with PPPL scientists on developing and implementing improvements

for gyrokinetic particle simulations. This work is directly related to the Numerical Tokamak Project effort.

- Dr. Mattor collaborated on drift wave propagation and edge turbulence problems with scientists at the Plasma Physics Laboratory of Kyoto University. He also visited NIFS.
- Dr. Fu worked at JAERI with both theorists and experimentalists on the stability of the toroidal Alfvén eigenmode (TAE) in their ICRF experiments on JT-60U. Using the NOVA-K code along with a local calculation of radiative damping, he was able to obtain encouraging results. He found that the calculated stability threshold agrees well with the experimental value (within a factor of two or three). The results show that the mode with toroidal numbers $n = 9$ or 10 is the most unstable mode, which is consistent with experimental observations. He also visited NIFS to discuss details of the nonlinear simulation of TAE modes with the Vlasov method and also to discuss HAE modes in stellerators. After returning to the US, he has continued his study on TAE stability in JT-60U and will soon finish a paper on this.
- Dr. Yagi worked at the the University of Wisconsin for three months and then at the IFS for nine months. His research dealt with neoclassical MHD and current-diffusive ballooning modes. During this time he was able to attend the APS Division of Plasma Physics annual meeting, the Transport Task Force annual meeting, the Sherwood Fusion Theory Conference, and the Numerical Tokamak Project annual meeting. In particular, he was chosen to give an invited talk at the Sherwood Meeting on his work. Two papers were written during his stay,[1,2] and several others are under preparation.

Also, a number of papers were published this past year by scientists who had participated in various activities of the JIFT program of the preceding year (1993-94).

- A productive research collaboration on turbulence-generated shear flow was continued, leading to results that have relevance to the L-mode to H-mode transition.[3-5] This work was also the basis for an invited paper at the 1994 IAEA Conference.[6]
- The relationship between well-known Monte Carlo techniques and the various low-noise particle simulation algorithms was explained[7] in a lucid way that makes clear why the δf algorithm has almost replaced full particle algorithms for fusion transport applications. Monte Carlo variance reduction methods were then applied to linear and nonlinear studies of pure electron plasmas, the low-noise techniques making it possible to follow the linear evolution and saturation of even very weakly unstable resonant diocotron modes.
- It was shown[8] that the damping of a circularly polarized Alfvén wave can drive current in a background plasma. The inverse process was shown to hold, viz., a decay of mean-field helicity that produces circularly polarized Alfvén waves. A fast, super-Alfvénic electron beam propagating along an ambient magnetic field and carrying net current can be the free energy source for this spontaneous conversion of plasma helicity to wave helicity. Because the background helicity induces a frequency shift in the eigenmodes, it becomes possible for a sub-Alfvénic electron beam to excite a nonsingular Alfvén mode.

- The linear damping rates of the toroidal ion temperature gradient mode due to the toroidal resonance were calculated in the local kinetic limit.[9] This research was motivated by the anomalous ion thermal transort observed in high temperature plasmas.
- Particle simulations were carried out[10] to investigate the effects of toroidal geometry on turbulence due to drift instabilities that are driven by density and temperature gradients. It was found that the increase of ion thermal conductivity with radius observed in experiments is possibly caused by the global nature of heat convection in the presence of toroidicity-induced mode coupling.
- A theoretical reformulation was constructed for the MHD description of a plasma, based upon the paradigm of current-carrying filaments.[11] This formulation is appropriate for the regime of very large Lundquist and Reynold's numbers. Novel two- and three-dimensional statistical equilibrium solutions were obtained, and low- or zero-frequency magnetic fluctuations were discovered in thermal equilibrium plasmas.
- A reduced set of neoclassical fluid equations was derived[12] that is valid for a fusion plasma with low to intermediate collisionality, in contrast to the earlier high-collisionality neoclassical fluid equations. These new equations were then used to invesitgate ion-temperature-gradient-driven modes in the neoclasical regime.
- A method to suppress the rotational instability of a field-reversed configuration with the use of injected beam ions was analyzed and applied to present or near-term experimental devices and a future reactor.[13] The results agree qualitatively with previous results from a hybrid particle simulation.
- A recent paper[14] found that the bootstrap current does not vanish, even in the collisional regime, when the aspect ratio approaches unity, thus showing that conventional theory underestimates the magnitude of the bootstrap current in an ultralow-aspect-ratio tokamak.

Incidentally, JIFT program activities are periodically publicized to the wider international fusion community through the *JIFT Newsletter*, which contains longer descriptions of the workshops, exchange visits, etc. The last issue was published in February of 1994, and a new issue is almost ready for distribution.

5. Plans for Future Activities

The topics and themes of the exchange activities that have been proposed for next year (April 1, 1995–March 31, 1996) are consistent with the traditional emphasis of JIFT on fundamental theoretical issues, but at the same time have relevance to mainline programmatic interests of both countries. These activities are listed in Attachment B.

One workshop and one scientific exchange visit concern “advanced tokamak” stability, a topic of high relevance, for example, to TPX, JT-60U (and Super Upgrade), ITER, and also the LHD and IMS stellarators. MHD stability has been a traditional area of JIFT activity ever since the beginning of this exchange program.

One workshop and four scientific exchanges concern new developments in computational methods, which, on the US side, are related to the Numerical Tokamak Project and, on the Japanese side, to their nonlinear plasma simulation program. The topic of computational physics has also been a continuing JIFT theme.

One workshop explores problems generic to the interaction of electromagnetic waves with plasmas, and hence is relevant to RF heating. This workshop is a follow-on to last year's workshop on a similar topic, which was reported to be quite successful.

One workshop and one exchange visit deal with certain fundamental transport and confinement phenomena, and hence are complementary, for example, to U.S. Transport Task Force efforts. This workshop was originally suggested to tie in with efforts of the ITER Expert Group on Transport Modelling.

One exchange visit continues a JIFT emphasis on the collective physics of fast ions and/or alpha particles, which is of relevance to present-day toroidal experiments with high auxiliary power for heating or current drive. This topic has become a recent area of emphasis in JIFT activities. It ties in with both the TTF Fast Particle Working Group and the ITER Expert Group on Fast Particles.

The joint computational projects, which comprise the third part of the JIFT program, usually arise as outgrowths of earlier workshops or scientific exchanges. Their number is periodically pruned, after their usefulness has been realized. For example, one joint computational project will be dropped after the 1994-95 program; it consisted of a 12-month visit by a theorist from JAERI to the IFS, after which the project was completed. Note that 3 of the proposed 11 joint computational projects for the coming year have JAERI scientists as participants.

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